Soil & Tillage Research, 4 (1984) 147—154
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

EFFECTS OF WHEEL TRAFFIC ALONG ONE SIDE OF CORN AND SOYBEAN ROWS *

N.R. FAUSEY and A.S. DYLLA

Soil Drainage Research Unit, USDA, ARS, 2073 Neil Avenue, Columbus, OH 43210 (U.S.A.)

(Accepted 27 June 1983)

ABSTRACT

Fausey, N.R. and Dylla, A.S., 1984. Effects of wheel traffic along one side of corn and soybean rows. *Soil Tillage Res.*, 4: 147—154.

There is a continuing need for information illustrating the seriousness of the soil compaction problem over a range of soils, climatic, and agronomic conditions and encouraging the adoption of controlled traffic. Compaction from wheel traffic adjacent to crop rows had significant effects on the soil physical conditions in Kokomo silty clay loam (Typic Argiaquoll) and on the corn (*Zea mays* L.) and soybean (*Glycine max* L.) yields. Traffic patterns were established to compare rows that had traffic on one side of the row with those that had traffic on neither side. These traffic patterns were followed for planting and spraying operations for a total of five passes. Corn had either no nitrogen fertilizer or adequate fertilizer and soybeans had no fertility variable. Bulk density and cone penetration resistance were significantly higher in the wheel tracks than in the untracked areas at the 0—15- and 15—30-cm depths. With adequate fertilizer, yields of corn and soybeans from rows along wheel tracks were equal to those from untracked areas. With no nitrogen fertilizer, corn yields were significantly lower from rows along wheel tracks.

INTRODUCTION

Modern farming practices are increasing wheel traffic and loading on agricultural soils. Eriksson et al. (1974) estimated that over an entire crop year the accumulated traffic over the soil averaged 4 to 5 times the soil surface area. During the past two decades, the size and weight of farm tractors and machines has increased with the growth in farm size; machinery companies have also provided larger tires which have increased soil contact area and therefore maintained or reduced soil-surface pressures. Soehne (1958) and Danfors (1974) showed that subsoil pressures are not reduced, however, and that the increased weight has increased the depth to which the pressures are transmitted even though contact pressure has not increased. Although the reduced surface pressures and increased traction resulting from larger tires may appear less damaging to soil at the surface, there will be

*Journal article No. 87-81 of the Ohio Agricultural Research and Development Center, Wooster, OH, U.S.A.

0167-1987/84/$03.00

greater likelihood for trafficking when the subsoil is wetter and more susceptible to compaction.

In humid climates excessive soil moisture limits the number of days available for tilling and planting (Reeve and Fausey, 1974). Central Ohio has an average annual rainfall of 95 cm, and there is, therefore, a high probability for soils to contain excess moisture during spring tillage and planting. This excess water problem places a high priority on improved drainage systems to increase the number of probable field working days required to avoid crop yield loss from delayed or late planting, but even with improved drainage systems, there remains a high probability that field areas will be trafficked when the soil is wet or in the plastic state within and below the tillage layer. Working or molding the soil when in the wet or plastic state reduces the volume of large pores and decreases rates of water and air movement. Grable (1967) also reported that root elongation rates decreased with decreasing soil porosity.

Trouse (1971) summarized the results of many studies of soil conditions and plant response and concluded that the effect of soil compaction on crop yield is indirect, depending on how the compaction effects the ability of the soil to supply the current needs of the plant. This effect will of course vary among soils and crops and from year to year with climatic changes. Cooper et al. (1969) showed clearly that controlled traffic gave higher cotton (*Gossypium hirsutum* L.) yields than without controlled traffic in a sandy loam in Alabama. A field compaction study in Ohio (Van Doren, 1959) clearly demonstrated corn (*Zea mays* L.) yield reductions on soil trafficked at a high moisture level. The entire plot area, row and inter-row, was compacted with a wheel tractor applying approximately 270 kPa track pressure. Voorhees (1979) reported that, except for root crops, crop yields in Minnesota (60-cm annual rainfall) were probably not being suppressed by normal soil compaction, and that moderate compaction in dry years has even resulted, in some cases, in increased soybean (*Glycine max* L.) yields.

Our field study on Kokomo silty clay loam in Ohio determined whether confining all post-planting wheel traffic to one side of crop rows caused a reduction in corn and soybean yields as compared to traffic on neither side. We did not consider the case of traffic on both sides of the row. Secondly, since crops are often subject to other stresses such as diseases, insect damage, drought, etc., what effect would a coupled second stress (lack of nitrogen) have on the response of corn to the wheel traffic treatment?

MATERIALS AND METHODS

Following harvesting of corn for grain in 1979, two areas (20 × 75 m) of Kokomo silty clay loam (fine, mixed, mesic Typic Argiaquoll) were fall plowed 25 — 30-cm deep. Prior to plowing, 112 kg ha^{-1} each of elemental phosphate and potash were applied. On 21 April 1980, when soil conditions were wet but appeared trafficable, one area was tilled 12 — 15-cm deep with a tractor rear-mounted field cultivator. Hybrid corn was then planted in 20-m long rows with a six-row rear-mounted planter. The corn was planted in 76-cm spaced rows for a population of 65 000 plants ha^{-1}. No fertilizer was applied at planting. Pre-emergence herbicide was applied the same day with a tractor-mounted sprayer retracking the wheel tracks made during planting.

On 22 May 1980, when the soil was again wet but appeared trafficable, the second area was likewise field cultivated and planted with soybeans in 76-cm spaced rows for a population of 344 000 plants ha^{-1}. Pre-emergence herbicide for weed control in the soybeans was also applied the same day, and following that operation all tractor tracks in both areas were retracked three times for a total of five passes.

The rear tire width of the tractor was 43 cm, leaving an average 16.5 cm distance between the edge of the tire track and the planted row. In planting, spraying and retracking tracks the 1.52-m spaced tractor wheels straddled rows 3 and 4 of the 6-row planter, leaving rows 1 and 6 without any tractor wheel tracks alongside. Crop yield samples for the wheel-tracked treatments were harvested from rows 3 and 4 of the six-row planter pass, and rows 6 and 1 of adjacent planting passes were the yield sampling rows for the non-tracked treatment. The rear-axle load of the tractor plus mounted equipment was 3.5 Mg, or 1.75 Mg per rear tire. Rear tires were inflated to 110 kPa. Planting, spraying and re-tracking speed was 1.1 m s^{-1}.

Half of the length of fifteen pairs of corn rows straddled by the tractors wheel-tracks, along with an equal length of an adjacent pair of nontracked corn rows, were fertilized on 4 June with 15—15—15 N—P—K fertilizer at the rate 1120 kg ha^{-1}. This granular-form fertilizer was hand applied and mixed into the top 4 cm of soil between rows 3 and 4 and rows 6 and 1 with a garden hoe. This shallow surface tillage with the garden hoe was performed on both fertilized and non-fertilized areas for uniformity. This fertilizer application was to assure that fertility would not be the limiting factor for half of the corn treatments. No additional fertilizer or tillage was applied to the soybeans. Therefore, the area planted with corn had four treatment comparisons: a complete factorial of fertility level (high or low) and adjacent wheel traffic (none or on one side only). The area planted with soybeans had only two treatment comparisons: rows adjacent or not adjacent to tractor wheel tracks. Details of traffic pattern, plot locations and replications are shown in Fig. 1 for the corn area. The layout for the soybean area was the same as that shown without the fertilizer treatments.

Soil water potential was measured at the 15- and 30-cm depths at six sites in both the corn and soybean areas at planting time with a Soilmoisture Model 2900 "Quick Draw"probe*. Irrigage tensiometers were installed after planting at these six locations (see Fig. 1) in the corn and soybean areas, to indicate continuously the soil water potential at the 30-cm depth. Represen-

*Mention of a trade name or proprietary product does not constitute a guarantee or warranty of the product by the USDA and does not imply its approval to the exclusion of other products that may also be suitable.

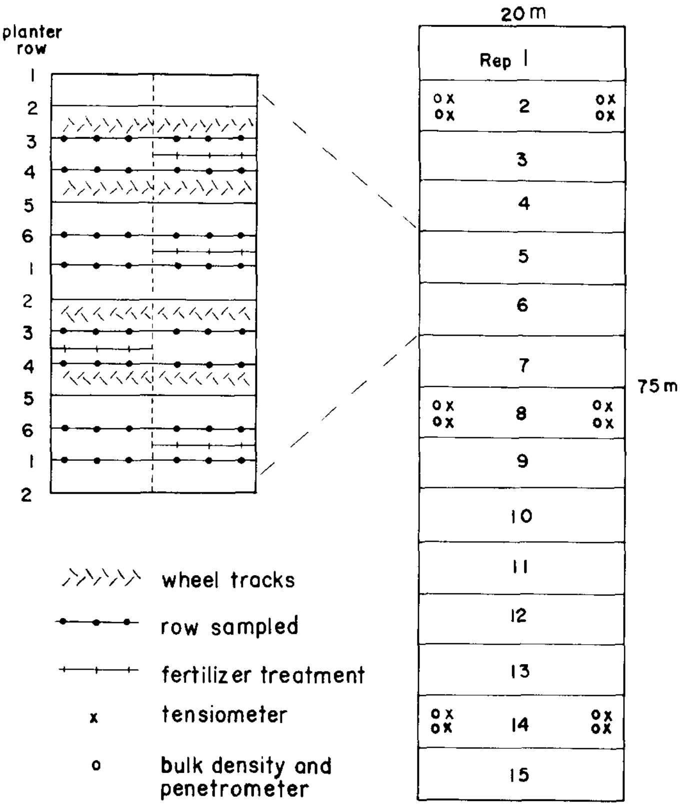

Fig. 1. Field plot layout showing treatment detail in two replications.

tative soil samples were collected from the 15-cm depth (10 — 20 cm) at planting time for soil water content determination, and also after the wheel tracks had been retracked the fifth time.

Soil strength or resistance was measured with a 30-degree cone penetrometer having a projected area of 323 mm^2 near each site where soil moisture was measured. Penetrometer measurements were made on 22 May (after completion of planting soybeans and a total of five wheel passes). Six replicated measurements were made at the 0 — 15- and 15 — 30-cm depths of the corn and soybean areas within and outside of the compacted wheel track, at each of the six locations shown in Fig. 1.

Dry bulk density was measured, in each of three 15-cm increments to 45 cm, in tractor wheel compacted and non-compacted areas near the site where soil moisture was measured. A sand-cone apparatus was used to measure the volume of an excavated hole. These soil samples were also used for laboratory determinations of texture and Atterberg limits as described by Lambe (1951).

Corn was harvested for yield determinations on 26 September. Yields were corrected to 15.5% moisture content. Soybeans were harvested in October for yield determinations. Only the eight odd numbered replicates of the soybean treatments were harvested and these yields were corrected to 13% moisture content.

After the remaining crop was removed from both areas, the hydraulic conductivity of wheel-compacted and non-compacted areas was measured with the air-entry permeameter described by Bouwer (1966), and modified by Topp and Binns (1976). The intake values were extremely high and it was impossible to measure air entry values; therefore, the apparatus was used as a falling head permeameter to measure the intake rate at several soil depths. Measurements were made at 0 — 10-, 30 — 40-, 60 — 70-, and 90 — 100-cm depths in the nontracked area and at 0 — 10- and 30 — 40-cm depths in the tracked area. For each depth, 3 — 5 separate locations were tested and 4 — 8 runs were conducted at each location.

RESULTS AND DISCUSSION

Soil condition effects

On the date of planting (21 April), the soil water potential and water content measured in the corn plot at the 15-cm depth averaged -14 kPa and 27.5%, respectively. The average soil water potential at the 30-cm depth was -1 kPa, and free water was detected at two of the six measurement locations.

The average soil water potential and water content measured on the day of planting (22 May) in the soybean plot for the 15 cm depth were -5.5 kPa and 29.4%, respectively. The average soil water potential at the 30 cm depth was -8.5 kPa. The average soil water content in the upper soil profiles during both plantings was between the upper and lower plastic limits (Table I), i.e., the soil was in a plastic, easily deformable state.

The soil penetration resistance values in Table II illustrate differences of compaction due to the tractor wheel traffic. The average soil water content at the 15-cm depth in the corn plot on 22 May was 26.5%. Statistically paired "*t*-test" comparisons showed a significantly greater penetrometer resistance at the shallow depth in the tractor wheel track than in the adja-

TABLE I

Soil water content and soil water potential at 15-cm depth at planting time compared with soil water contents for Atterberg limits[a] of the test Kokomo silty clay loam

Date	Statistical parameter	Soil water potential (kPa)	Soil water content (% (w/w))		
			15 cm	UPL	LPL
21 April 1980 (corn)	Mean	-14	27.5	30.9	24.7
	Std. error	- 4.8	2.35	2.58	1.86
22 May 1980 (soybeans)	Mean	- 5.5	29.4	32.8	24.0
	Std. error	- 3.7	2.30	0.54	1.20

[a] Atterberg limits: upper plastic limit, UPL; lower plastic limit, LPL.

TABLE II

Plot summaries of maximum cone penetration resistance and bulk density measurements on Kokomo silty clay loam following five tractor wheel retrack passes (22 May). The average water content, % (w/w), at 15-cm depth at the time of sampling was 26.5% in the corn plot and 29.4% in the soybeans plot

Depth (cm)	Statistical parameter	Bulk density ($Mg\ m^{-3}$)		Resistance (kPa)	
		Track	No track	Track	No track
Corn					
0—15	Mean	1.52[a]	1.29	1 390[a]	800
	Std. error	0.06	0.10	270	180
15—30	Mean	1.52[b]	1.39	1 670	1 620
	Std. error	0.05	0.09	210	240
30—45	Mean	1.50[a]	1.47		
	Std. error	0.07	0.05		
Soybeans					
0—15	Mean	1.50[a]	1.22	690	730
	Std. error	0.06	0.13	150	140
15—30	Mean	1.49[a]	1.35	1 850	1 640
	Std. error	0.06	0.12	250	280
30—45	Mean	1.48	1.51		
	Std. error	0.12	0.06		

[a] Different from non-compacted at 1% level.
[b] Different from non-compacted at 5% level.

cent nontracked soil. Water content probably had a greater effect on the strength than density because the maximum penetration resistance in the 15- to 30-cm depth on the corn plot did not significantly increase with compaction (Table II).

Bulk densities (Table II) measured with the sand cone apparatus at the same locations as the penetration measurements also illustrate the effect of tractor wheel compaction. Soil bulk density was significantly greater at the 0 — 15-cm and 15 — 30-cm depths below the tractor wheel track than at the same depths in the nontracked areas. There was no difference in bulk density at the 30 — 45-cm depth below the tracked and nontracked sampling sites. Differences in preplant tillage and planting dates for the corn and soybean plots may have affected the soil moisture conditions and the resultant compacted densities for the two plots. There were no significant bulk density differences between corresponding profile depths of the non-compacted corn and soybean plots.

Observations of crop rooting at the time of bulk density measurements indicated no corn rooting activity in the 0 — 15-cm layer under the wheel track (compacted). However, corn rooting did extend under the wheel track at the interface of the plow layer and the subsoil. Incorporated crop residues may have resisted consolidation associated with compaction and therefore maintained soil aeration. Soybeans did not exhibit a similar rooting behavior.

Because of the extensive soil shrinkage cracks, it was difficult to obtain a hydraulic conductivity measurement of the surface soil until after appreciable rain. Even then, hydraulic conductivity for untracked sites ranged from 5.94 to 70.8 $\mu m\ s^{-1}$. Hydraulic conductivity of the surface soil compacted by the wheel track ranged from 1.53 to 60.0 $\mu m\ s^{-1}$. The average hydraulic conductivity was 22.8 $\mu m\ s^{-1}$ at the 30-cm depth of wheel tracked sites and 28.6 $\mu m\ s^{-1}$ at nontracked sites. A measured rate of 33.6 $\mu m\ s^{-1}$ at the 61-cm depth of a non-tracked site sharply contrasted with the measured 8.1 $\mu m\ s^{-1}$ rate at the 91-cm soil depth. However, this difference was attributed to the pronounced absence of earthworm channels at the lower depth.

Yield effects

Soil water potential at the 30-cm depth, as monitored with the Irrigage tensiometers, never exceeded -85 kPa during the entire crop growing season, thereby indicating adequate soil moisture for the crops. Crop yields (Table III) indicate that if fertility and moisture are not limiting, yields are not likely to be depressed by the presence of a compacted wheel track along one side of the row. However, significant yield differences were obtained for the corn where the supplemental fertilizer was not applied. The presence of a compacted wheel track alongside these corn rows resulted in 11% lower yields than from rows with no traffic alongside. This would amount to 0.3 $Mg\ ha^{-1}$ corn yield reduction if four out of every six rows had wheel traffic along one side. With 8- and 12-row width tillage, planting and harvesting machinery, and a controlled traffic pattern the reduction would be proportionately less.

TABLE III

Corn and soybean yields from 76 cm spaced rows, with and without a compacted wheel track along one side of row, and for two fertility levels on the corn plot

Crop	Statistical Parameter	Yield ($Mg\ ha^{-1}$)	
		Track	No track
Corn (adequate fertility)	Mean	11.83	11.61
	Std. error	0.47	0.66
Corn (low nitrogen)	Mean	3.56[a]	4.01
	Std. error	0.66	1.10
Soybeans	Mean	3.01	2.97
	Std. error	0.16	0.13

[a] Different from no track at 5% level.

The most important aspect of the results is that neither soybeans nor well fertilized corn suffered yield reductions due to five passes of the tractor wheels along one side of the crop row. Inter-row wheel traffic compacted the soil significantly in the top 30 cm of the soil profile, but did not appear to have affected the hydraulic conductivity below the plowed depth. It was obvious from measurements and visual observations that earthworm channels greatly enhanced movement of water through the soil. The presence of earthworm activity in this silty clay loam with bulk density near 1.5 Mg m^{-3} indicates the potential for maintaining soil aeration and drainability.

This study also suggests that any detrimental effects of wheel compaction on yield may be minimized substantially if wheel traffic is confined to the crop inter-row area and on one side only. If all farming operations could be conducted without disturbing the compacted soil paths, energy expended to re-plow, re-till and re-compact areas traversed by the wheels could represent significant savings.

REFERENCES

Bouwer, H., 1966. Rapid field measurement of air entry value and hydraulic conductivity of soil as significant parameters in flow system analysis. Water Resour. Res., 2: 729—738.

Cooper, A.W., Trouse, A.C. Jr. and Dumas, W.T., 1969. Controlled traffic in row crop production. Proc. 7th Int. Congr. of C.I.G.R., Baden-Baden, Germany, pp. 1—6.

Danfors, B., 1974. Compaction in the subsoil. Translation from: Spec. Bull., S 24 1974. Swedish Institute of Agricultural Engineering Ultuna, Uppsala, 91 pp.

Eriksson, J., Hakanson, I. and Danfors, B., 1974. Effect of soil compaction on soil structure and crop yields. Swedish Institute of Agricultural Engineering Bull. 354, 101 pp.

Grable, A.R., 1967. Effects of tillage on soil aeration. Conf. Proc.: Tillage for Greater Crop Production, ASAE, St. Joseph, MI, pp. 44—46, 55.

Lambe, T.W., 1951. Soil Testing for Engineers. Wiley, New York, pp. 22—42.

Reeve, R.C. and Fausey, N.R., 1974. Drainage and timeliness of farming operations. In: J. van Schilfgaarde (Editor), Drainage for Agriculture. Am. Soc. Agron., Monogr. No. 17, pp. 55—66.

Soehne, W., 1958. Fundamentals of pressure distribution and soil compaction under tractor tires. Agric. Eng., 39: 279—281, 290.

Topp, G.C. and Binns, M.R., 1976. Field measurement of hydraulic conductivity with a modified air-entry permeameter. Can. J. Soil Sci., 56: 139—147.

Trouse, A.C. Jr., 1971. Soil conditions as they affect plant establishment, root development, and yield. In: K.K. Barnes, H.M. Taylor, R.I. Throckmorton and G.E. Van den Berg (Editors), Compaction of Agricultural Soils. Am. Soc. Agric. Eng., St. Joseph, MI, pp. 225—276, 306.

Van Doren, D.M. Jr., 1959. Soil compaction studied to determine effect on plant growth. Ohio Farm Home Res., 44: 317 (Ohio Agric. Exp. Stn., Wooster, OH).

Voorhees, W.B., 1979. Soil tilth deterioration under row cropping in the northern corn belt: influence of tillage and wheel traffic. J. Soil Water Conserv., 34: 184—186.